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Ambient Noise Measurements in and Around the Gulfport Mississippi Harbor and Its Potential Influence on Marine Mammals

STEVE STANIC

ROBERT A. BROWN

EDGAR T. KENNEDY

DEXTER A. MALLEY

*Acoustic Simulation, Measurements, and Tactics Branch
Acoustics Division*

MOBASHIR A. SOLANGI

*Institute for Marine Mammal Studies
Gulfport, Mississippi*

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14. ABSTRACT A pilot program designed to measure ambient noise and record dolphin echolocation signatures at the entrance to the Gulfport harbor was carried out from May 2005 to July 2005. This non-invasive study used a passive acoustic monitoring system. These results showed that during the month of May, dolphin echo ranging clicks were easily identified by their broadband spectra and in many cases correlated with visual observations of dolphin activity in the area. Signatures of large and small ships entering and leaving the harbor area were also recorded. The animals did not appear to be affected by the noise generated by the small boats. However, when several large container ships entered and left the Gulfport harbor, there was little evidence of any dolphin echolocation signals and no dolphin were observed in the immediate area. Their absence may be due to the high levels of broadband noise radiated from these ships. These long-term observations also show that, even after sunset, dolphin echolocation signals were recorded indicating that the animals are continuing to be active during the nighttime hours.					
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I. Introduction: Over the past several years, there has been an increase in the levels of man made noise pollution introduced into the marine environment. These are the result of increases in maritime shipping, geophysical surveys, dredging, oceanographic surveys and military testing. There is concern that these increased levels of broadband noise could disrupt the ability of dolphins to communicate and echolocate, and may cause either temporary or permanent hearing thresholds shifts [1,2]. There is also the possibility, that high levels of broadband noise may cause physiological damage to dolphin sensory and other body organs [3].

Adverse effects on dolphin hearing and migration from anthropogenic noise include, but are not limited to, (a) masking of dolphin vocalization and signature interference with dolphin sonar [4,5], (b) changes in dolphin behavioral patterns relating to navigation, migration, reproduction, and feeding, (c) influences leading to stranding, and (d) physiological impairment of their hearing and / or echolocation, or navigation abilities, from auditory structural damage. Item (b) includes the fact that pregnant females are known to move into shallow water areas for birthing, where shark predation of juvenile dolphin is more restricted, and deals with the issue of noise interference of mother-calf interaction and learning [6-9].

Figure 1 compares noise levels and different dolphin hearing thresholds with the ambient noise measured in San Diego harbor. This plot shows that the ambient noise in San Diego harbor is higher than the bottlenose dolphin threshold measured by Johnson [10], but lower than the measured threshold for striped dolphin [11]. If the ambient noise were to increase due to increased shipping, (Table I) or increased use of pleasure crafts, it could also shift the hearing thresholds of the stripped dolphins.

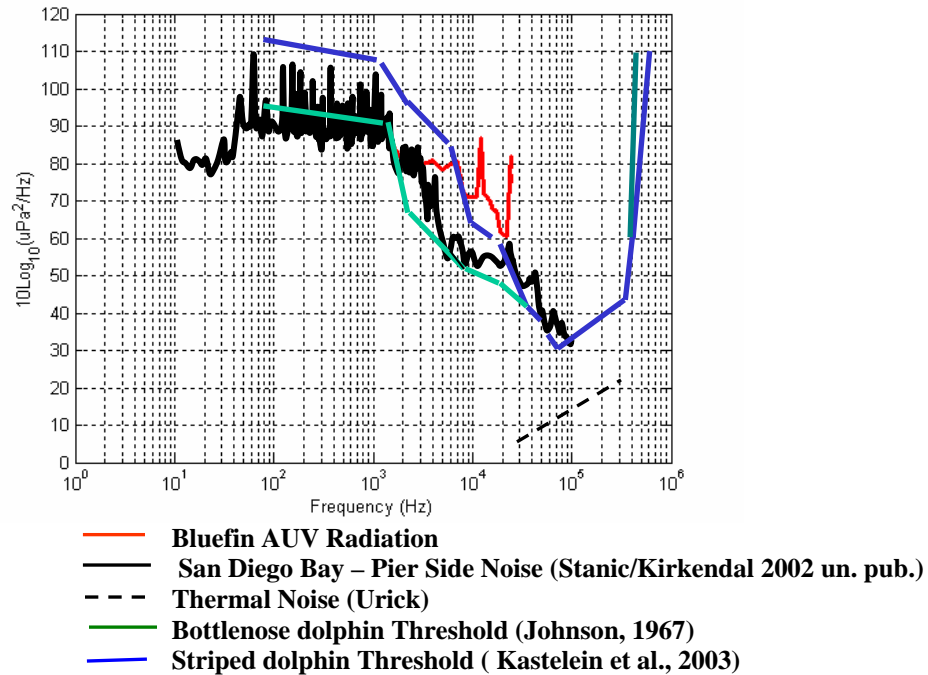


Figure 1. Noise spectrum levels and dolphin noise thresholds

Table I. Radiated noise levels for various ships vs speed at 5 kHz [12].

Speed (knts)	5	6	7	10
Ship type				
Passenger	93 dB	100 dB	103 dB	115 dB
Tankers	115 dB	116 dB	117 dB	118dB
Freighters	109 dB	110 dB	112 dB	116 dB

Near shore and harbor ambient noise characteristics can be significantly different from deep water ambient noise. Most deep water ambient noise is a result of different sea states, and can be estimated from the familiar Wentz curves [12]. However, the noise in shallow coastal and harbor areas, is generally caused by high commercial shipping concentrations, pleasure crafts, and other environmental causes. These could include low-frequency highway noise, and other terrestrial noise sources and do not strictly follow the Wentz curves. Few near-shore measurements of ambient noise levels have been made in the Gulf of Mexico.

The impact of anthropogenic acoustic noise on the hearing of bottlenose dolphin (*Tursiops truncatus*) in the Mississippi Sound is not well known. An actual determination of the effects of anthropogenic noise on dolphin behavior requires a more detailed knowledge of issues such as; noise mechanisms, source distribution, dolphin population distributions, migratory habits, and vocalization characteristics.

This report documents the results of a pilot study designed to determine the feasibility of monitoring bottlenose dolphin 24 hours a day, 7 days a week at the entrance to the Gulfport harbor. The primary task concentrated on the measurement, and analysis, of noise recorded in this area. These measurements also have the potential to correlate changes in ambient noise levels, with dolphin population numbers in these areas. It also documents the activity of dolphins during the evening and early morning hours.

II. Experimental Area: Figure 2 shows a schematic of the entrance to Gulfport harbor, and the position of the ambient noise measurement system that was deployed from June 2005 to August 2005. The water column during that time was isovelocity, with water temperatures approaching 85 degrees. The measurement system was deployed about 250 m from the pier, and was near the edge of the shipping channel, where the water depth was about 10 m. An instrumentation van was located on one of the harbor piers. This area is known to be frequented by numerous dolphins on their morning and evening runs along the coastline. The Mississippi sound and adjacent waters harbors a very large dolphin population [6] and are frequently seen throughout the year. They are constantly seen around piers and harbors

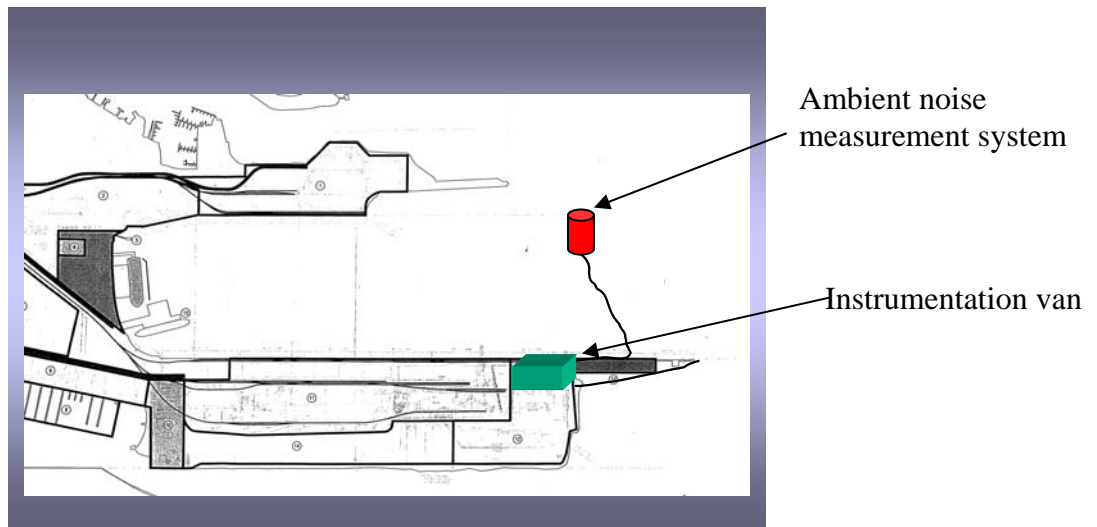


Figure 2. Gulfport harbor and position of the ambient noise measurement system

III. Measurement system: The measurement system used a RESON broadband hydrophone with a receiving sensitivity that ranged from -145 dB re $1\text{v}/\mu\text{Pa}$ at 10 kHz to -148 dB re $1\text{v}/\mu\text{Pa}$ at 100 kHz. The hydrophone was mounted on top of a nylon instrument canister. The canister was mounted inside a 200 lb trawl resistant concrete base. Two cables were run to the deployed measurement system. The first supplied power, and the second, a fiber optic cable, carried the raw data signals back to the instrumentation van. Photographs of the measurement system are shown in Figure 3.

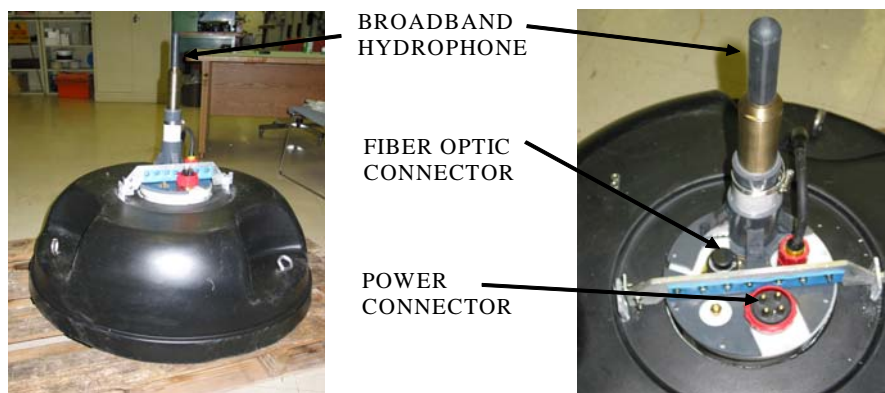


Figure 3. Ambient noise measurement system

Figure 4 is a schematic of the data acquisition and processing systems located inside the van. The signals from the hydrophone were amplified and bandpass filtered from 10 kHz to 100 kHz. This band width was selected to limit the digitizing frequency, and limit the amount of data that was acquired over the 90 day monitoring period. The signals were digitized at a 300 kHz sampling rate using a National Instruments MIO-16 A/D system. A 4096 point FFT was computed, and 40 of these spectra averaged to produce a

0.54 sec long average spectrum. This data was which was stored for display further analysis and display. Continuous data was acquired for 15 minute periods after which the data acquisition system shut down for 15 minutes. This process was repeated 24 hours a day for about 3 months.

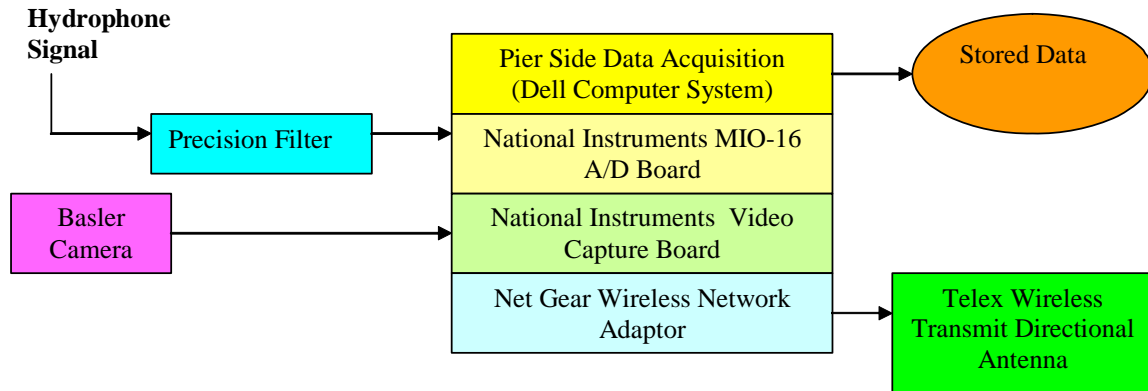


Figure 4. Pier side data acquisition and processing system

Located on top of the van was a small Basler Video Camera. This camera was pointed in the direction of the measurement system, and was used for visual monitoring of the measurement area. These images, as well as the averaged acoustic spectrum, were transmitted to the The Institute for Marine Mammal Studies (IMMS) facilities that were located at Marine Life Oceanarium in Gulfport Mississippi via a high-speed wireless connection. This provided the capability to remotely monitor the acquisition process. Figure 5 is a diagram of the instrumentation located at The Gulfport facilities.

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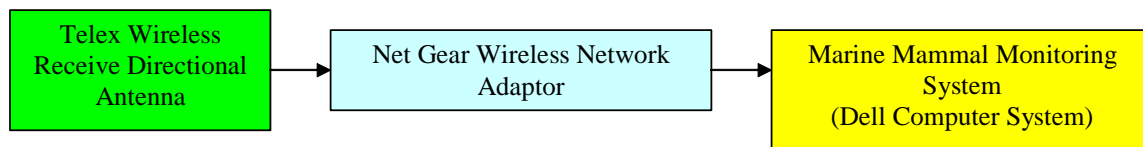
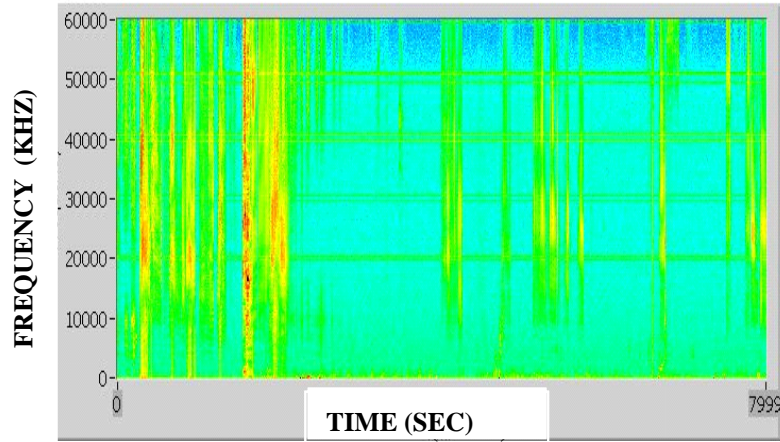


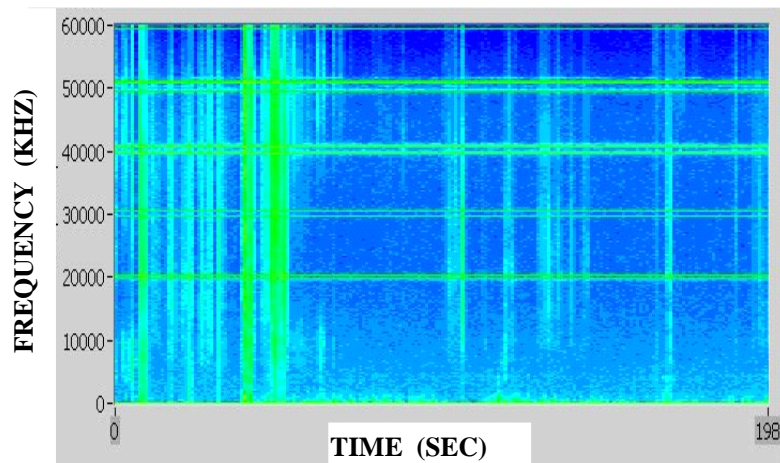
Figure 5. Monitoring system located at IMMS

Since the system was designed for long term monitoring of dolphin acoustic signatures (clicks and whistles) [16], the displayed spectra were an average of 40 calculated spectra. This averaging technique was tested using a series of signals recorded in the dolphin holding tanks at the Marine Life Oceanarium. The tank signals were recorded, band passed from 1 kHz to 60 kHz, and the spectra calculated for each individual click.

These results are plotted as a function of time in Figure 6 (a), and shows the broadband spectra of each of the individual clicks over a 7,999 second time frame. In these plots the broadband spectral characteristics of the dolphin signal are clearly seen. Figure 6(b) shows the same results after the averaging process. It was clear that even after the averaging process, the characteristic signatures of the dolphin echolocation clicks are still clearly visible. The persistent frequency lines at 20, 30, 40 and 50 kHz are a result of electrical interference around the tank.



(a)



(b)

Figure 6. Broadband dolphin spectra before and after spectral averaging

IV. Results and discussion. The measurement system was deployed from June through August 2005. During that time, data was continuously recorded until it was inadvertently

destroyed by a harbor dredge. Throughout this time period, the area was traversed by small fishing boats, pleasure craft, and large container ships entering and leaving the Gulfport harbor. These large vessels entered the harbor mainly during the day time hours, and only one or twice a week. The results presented in this report were recorded from May 19 through May 23 and are representative of the data recorded over the entire time period.

Table II list the bandwidths for the echolocation click and whistles emitted by different dolphin species. In general the echolocation clicks have a bandwidth ranging from 1 kHz to about 160 kHz. Recent, measurements show some dolphin clicks having bandwidth approaching 200 kHz [14]. The whistles, signals that are used for communications, have a much lower band width. These range from 1 kHz to about 25 kHz depending on the species. The ambient noise levels at the harbor location were low, ranging from 70 to 75 dB, and are similar to measurements reported by Anderson and Gruber [15].

Table II. Dolphin signal bandwidths [16]

Scientific Name	Common Name	Signal Type	Frequency Range (kHz)	Frequency Near Maximum Energy (kHz)	Source Level (dB re:1 μ Pa)
<i>Stenella attenuata</i>	Spotted dolphin	Whistles	3-21	7-18	-
<i>Stenella clymene</i>	Clymene dolphin	Whistles	6-19	-	-
<i>Stenella ceruleoalba</i>	Spinner dolphin	Whistles Pulse bursts	1-23	5-60	109-125
<i>Stenella longirostris</i>	Long-snouted spinner dolphin	Pulse Whistle Click	1-160 1-20 1-160	5-60	-
<i>Stenella plagidon</i>	Spotted dolphin	Whistles Clicks	5-20 1-8	7-18	-
<i>Stenella styx</i>	Gray's porpoise	Whistles	6-24	8-13	-
<i>Steno bredanensis</i>	Rough-toothed dolphin	Whistles Click	4-7 5-32	4-7	
<i>Tursiops truncatus</i>	Bottlenosed Dolphin	Whistles Clicks	1-24 10-160	4-15 110-130	218-228

May 19: The following three figures show typical dolphin and background shipping noise spectra recorded on May 19. These data indicate the presence of ships in combination with dolphin echolocation clicks. Figure 7 shows the averaged spectra calculated over a 15-minutes beginning at 18:58, on the evening of May 19. During this time period, the background ambient noise levels were low, indicating little shipping activity in and around the harbor. In figure 7 the broadband dolphin spectra are clearly visible at about the 8-minute mark. The broadband spectra were consistent with observed dolphin activity in the harbor area. During this time period, the spectra varied in intensity.

This suggest that the animals were either some distance from the measurement system, or their sonar, which can be directional [17], was not directed towards the measurement system.

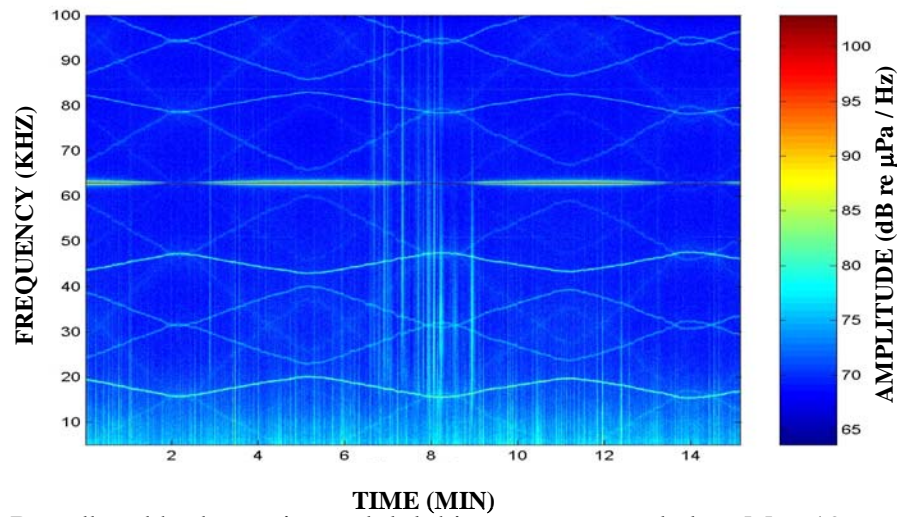


Figure 7. Broadband harbor noise and dolphin spectra recorded on May 19 beginning at 18:58

The 64 kHz line seen in the figure was generated from the switching power supply located in the data acquisition canister. The origin of the other frequency harmonics that were often present, is not clearly understood. A post analysis of the system noise was not possible due to the loss of the system.

Figure 8 shows the spectra for a 15-minute interval that was recorded about 2 hours later. Again the signal spectra vary in intensity, with a peak level occurring at about the 5-minute mark. This plot also show the presence of other the high-frequency echolocation clicks during the monitoring time.

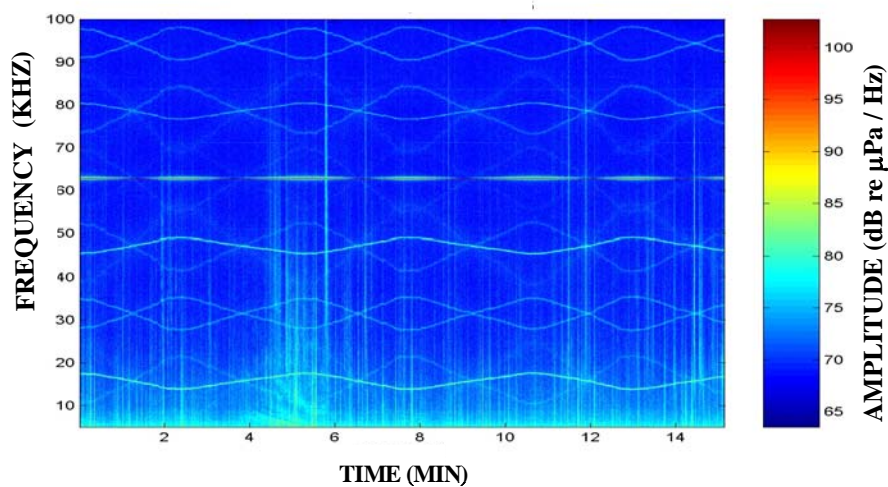


Figure 8. Broadband harbor noise and dolphin spectra recorded on May 19 beginning at 20:58

Figure 9 shows the spectra for a 15-minute monitoring period 2 hours later. At this time there was an increase in the dolphin activity during the first 7-minutes. These late night monitoring periods show dolphin activity in and around the harbor area, late into the evening hours. Until this time, it was not clear what dolphin activity took place after sunset. However, as these observations indicate, dolphin are quite active throughout the night time hours.

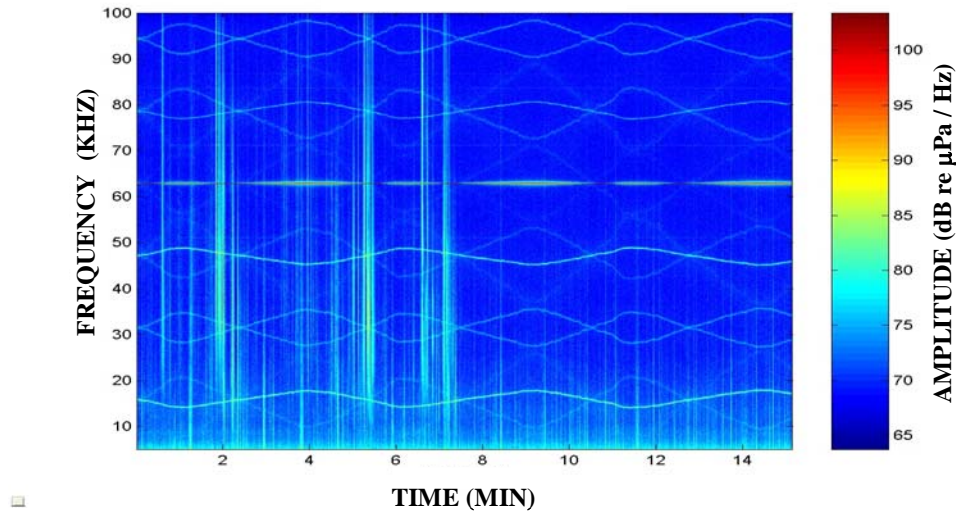


Figure 9. Broadband harbor noise and dolphin spectra recorded on May 19 beginning at 22:58

May 20: The following four figures show 15-minute average spectra for monitoring periods on May 20. Figure 10 shows the classic spectra of a small boat present in the harbor area very early in the morning, and very close to the measurement system. During this time period no dolphin activity was recorded.

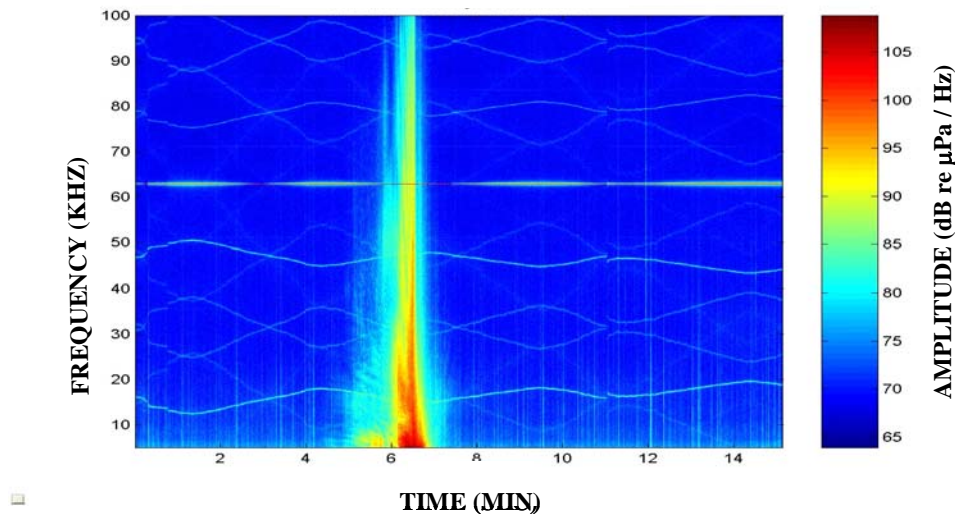


Figure 10. Broadband harbor noise and small boat spectra recorded on May 20 beginning at 04:28

At about 8 am, on May 20 a large container ship was leaving the Gulfport pier. This departure usually lasted about an hour and the intense spectra of the ship is clearly seen in Figure 11. During this period, there was no evidence of any marine mammals in the area. It is not clear whether the animals were never present or they departed the area when the ship got underway.

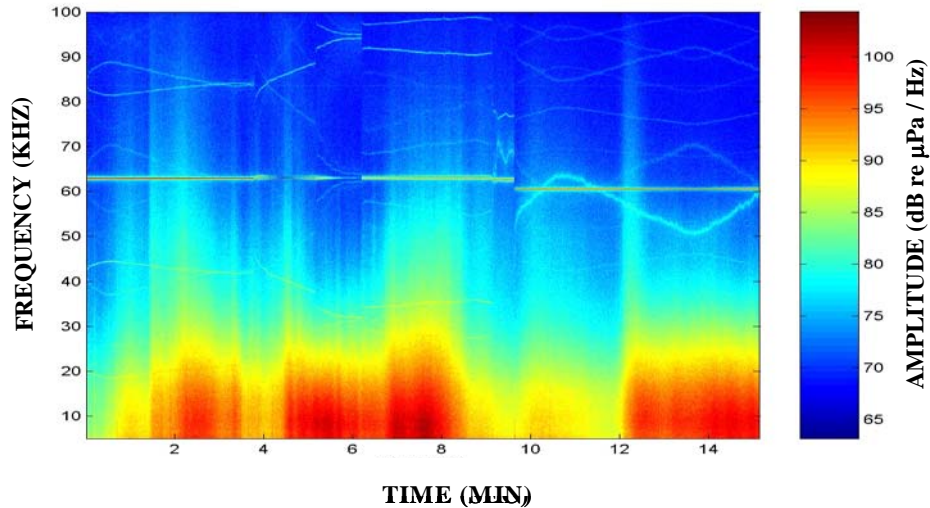


Figure 11. Broadband harbor noise and container ship spectra recorded on May 20 beginning at 07:58

In the evening of May 20, broadband echolocation signals consistent with dolphin activity in and around the harbor were again detected and recorded. During this 15-minute monitoring period, shown in Figure 12, the animals appeared very active and were echo locating on numerous targets during this 15 minute period. The intense line at the 11-minute mark may be the result of a dolphin in close proximity to the measurement system.

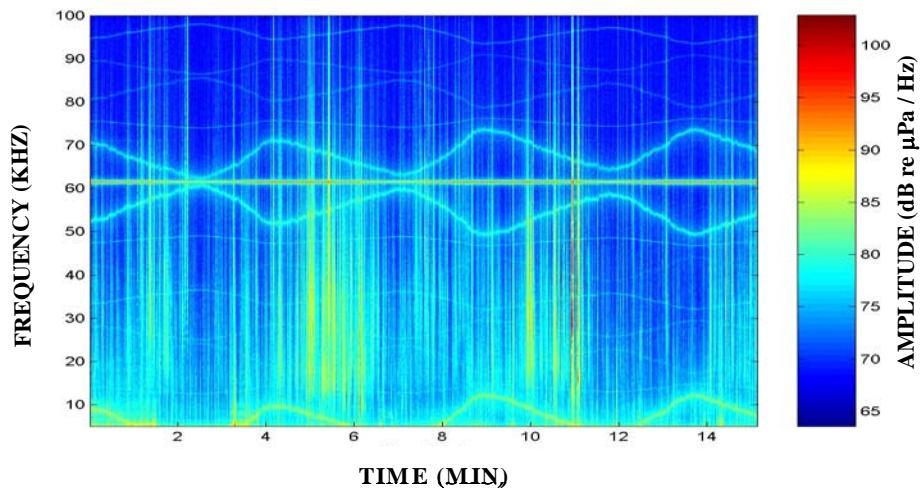


Figure 12. Broadband harbor noise and dolphin spectra recorded on May 20 beginning at 20:28

Figure 13 show the results of a monitoring period 30 minutes later. At the beginning, the spectra are intense with bandwidths of at least 100 kHz. The animals are clearly in close proximity or directing their sonar at targets close to the measurement system. Later in the period there are several signals with bandwidths of only 60 kHz to 70 kHz.

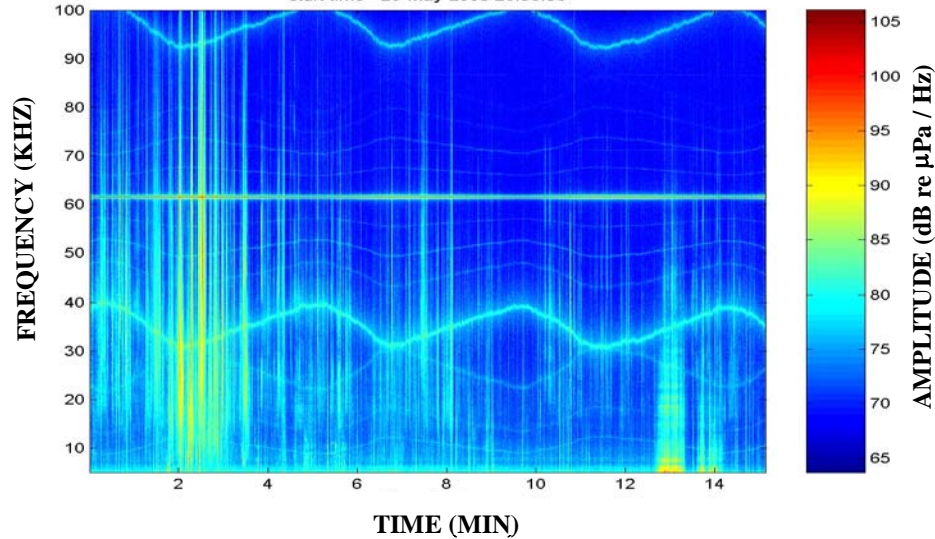


Figure 13. Broadband harbor noise and dolphin noise spectra recorded on May 20 beginning at 20:58

May 21: Early in the morning of May 21, the system detected a small boat leaving or entering the harbor area, (Figure14). During this monitoring period, no dolphin echolocation signatures were recorded.

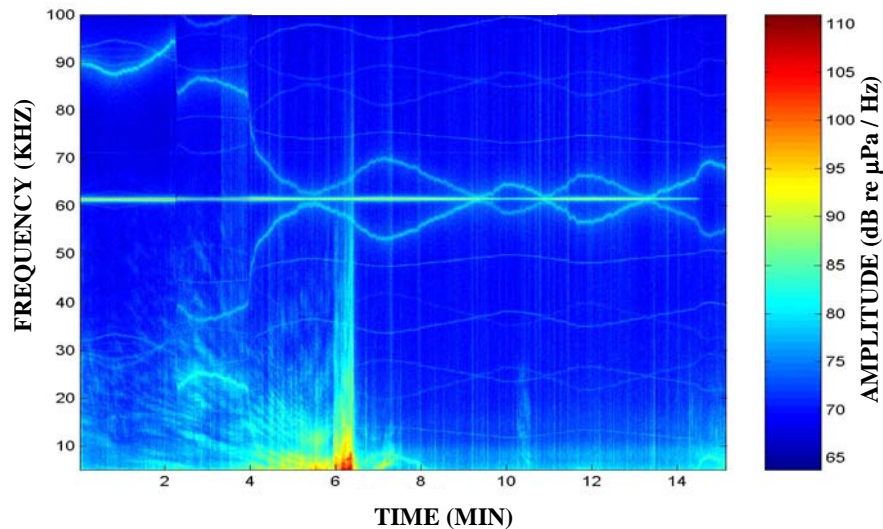


Figure 14. Broadband harbor noise and small boat spectra recorded on May 21 beginning at 06:59

Later in the morning, at 08:29, the broadband dolphin echolocation signals are again clearly visible as shown in Figure 14, and correlated with visual observations. At several times during this period, the spectra were very intense, especially in the 1 to 15 kHz band.

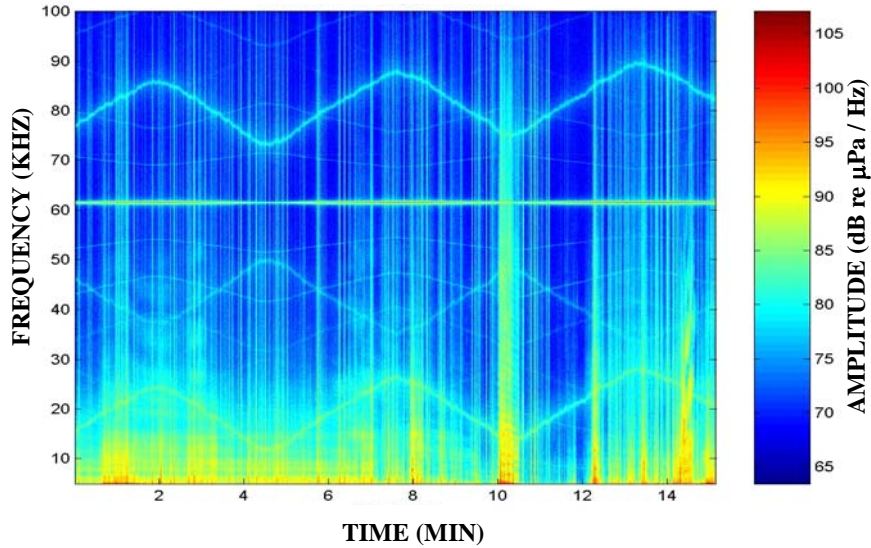


Figure 15. Broadband harbor noise and dolphin spectra recorded on May 21 beginning at 08:59

At 10:59 (Figure 16), several different spectra that were recorded. During the first two minutes the data shows a small boat in the area. After which echolocation signals are observed. At about the 7-minute mark there are several strong broadband spectra that do not have the signature of a small boat (Figure 10). This is most probably a series of clicks directed at targets in the area. Several strong echolocation signals are evident at the 7-minute mark, and again at the 11-minute mark

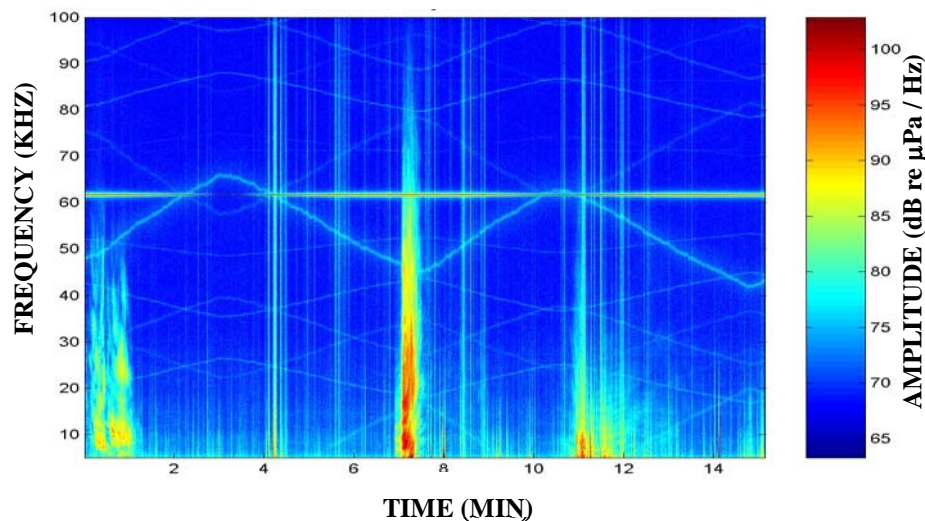


Figure 16. Broadband harbor noise, small boat, and dolphin spectra recorded on May 21 beginning at 10:59

At 13:59 on May 21, a large container ship was again observed leaving the Gulfport harbor. Figure 17 shows this signature with its intense characteristic high / low-frequency levels. The high levels occurred when the ship was going through its initial maneuvering sequences. The levels recorded later in the period are from the same ship, but as it exits the harbor. During this monitoring period no dolphin were visually observed and no signatures recorded.

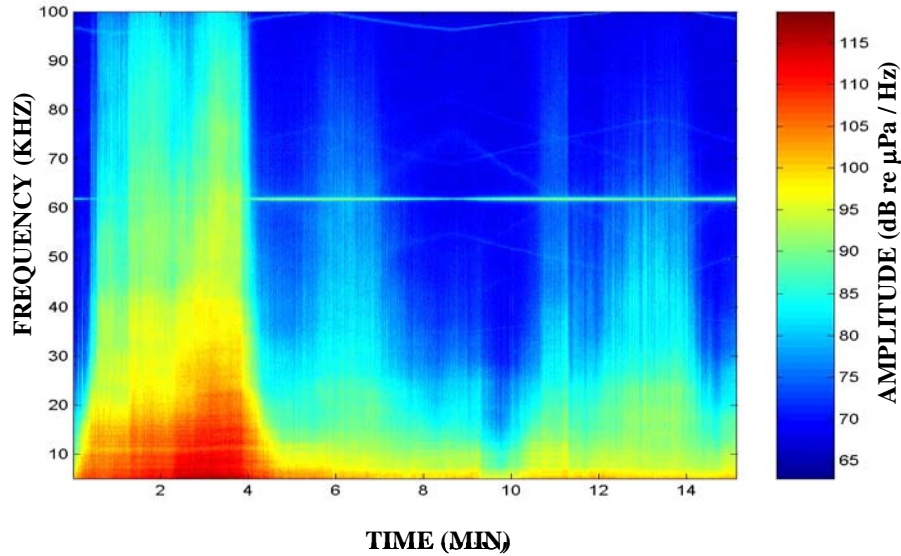


Figure 17. Broadband harbor noise and container ship spectra recorded on May 21 beginning at 13:59

In the early evening on May 21, a small boat was in the area followed by an increase in dolphin activity around the 11-minute mark (Figure 18). There may also have been several other small boats in the area at the 5 and 11-minute marks.

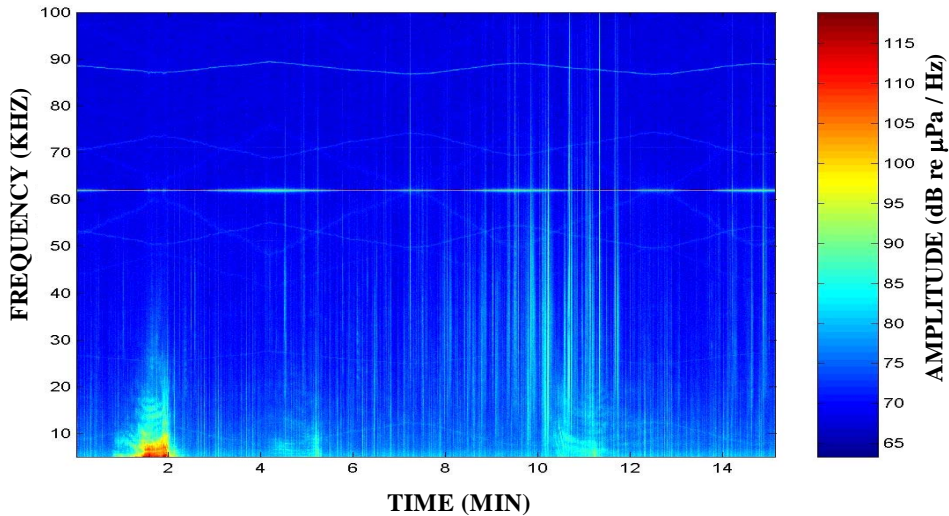


Figure 18. Broadband harbor noise, small boat, and dolphin spectra recorded on May 21 beginning at 20:29

May 23: In the early morning hours of May 23, the data showed dolphin activity in and around the harbor area,(Figures 19 and 20). These data are some of the first observations of dolphin activity during the evening and early morning hours.

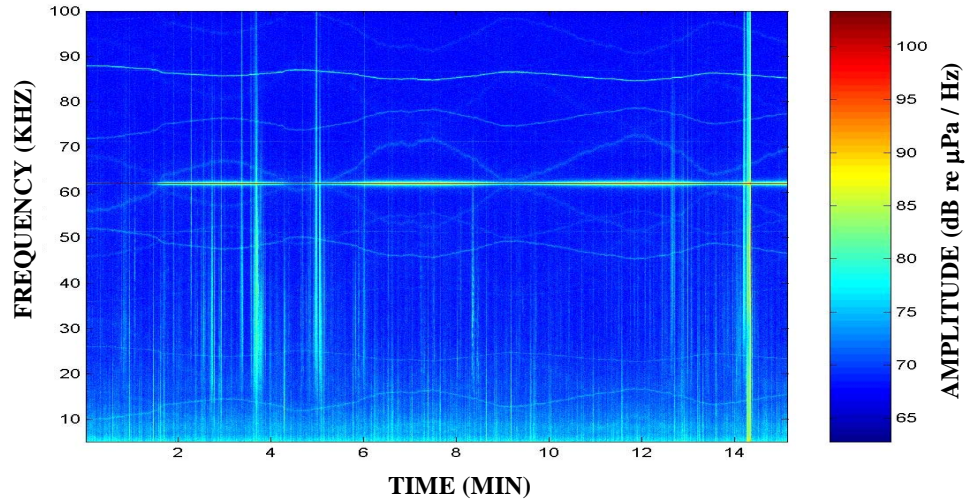


Figure 19. Broadband harbor noise and dolphin spectra recorded on May 23 beginning at 03:29

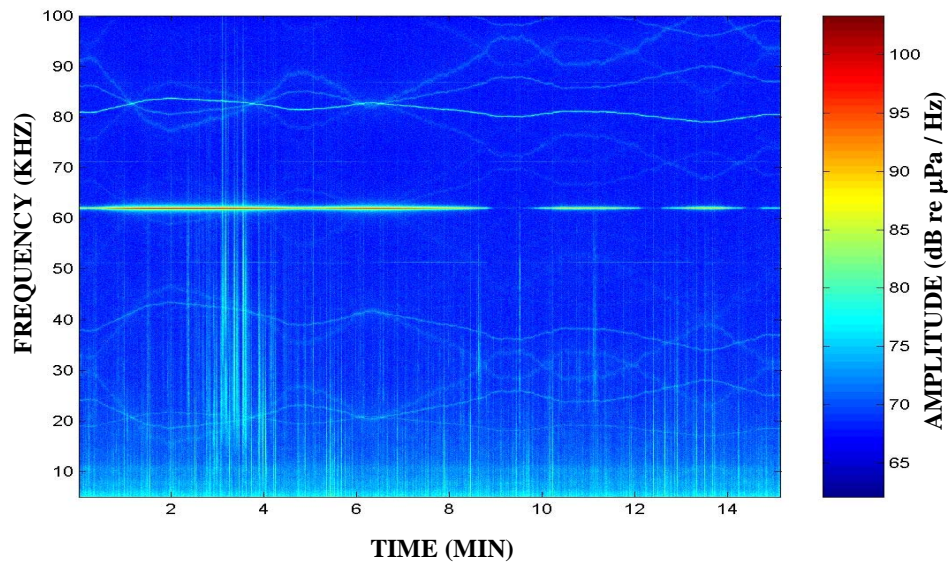


Figure 20. Broadband harbor noise and dolphin spectra recorded on May 23 beginning at 04:29

At about noon on May 23 a period with a considerable amount of small boat traffic was visually observed and their signatures were recorded. These results are shown in Figure 21. A small pleasure craft, and a small fishing boat were both observed slowly leaving the harbor area. In both cases the intense portions of the signatures band widths were about 50 kHz. No dolphin activity was detected during this monitoring period.

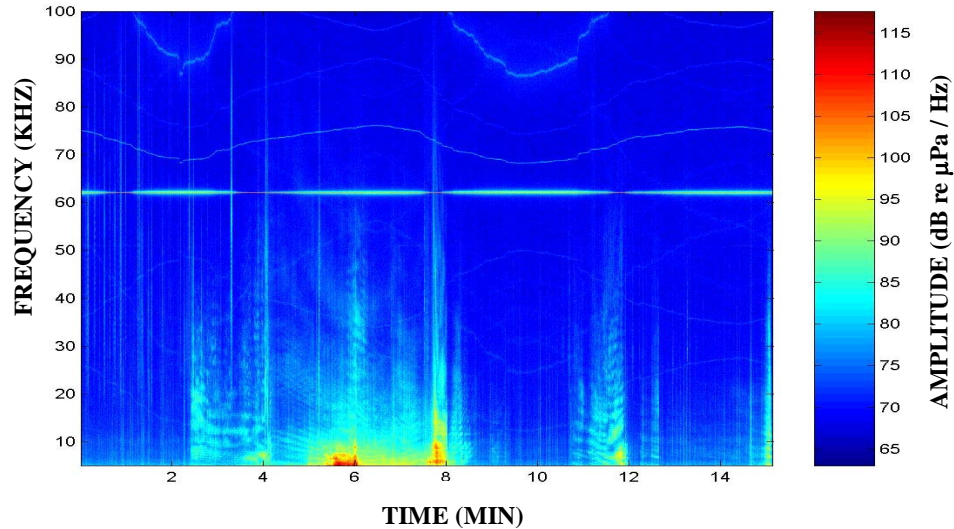


Figure 21. Broadband harbor noise and small boat spectra recorded on May 23 beginning at 11:59

Later in the afternoon of May 23, small boat traffic was recorded, (Figure 22), at the 3 and 8-minute times. However, at the 14-minute mark, a strong broadband spectral line was observed. This was very likely the broadband spectra of dolphin echolocation clicks, in close proximity to the measurement system. Some of the other broadband lines were also likely due to dolphin activity.

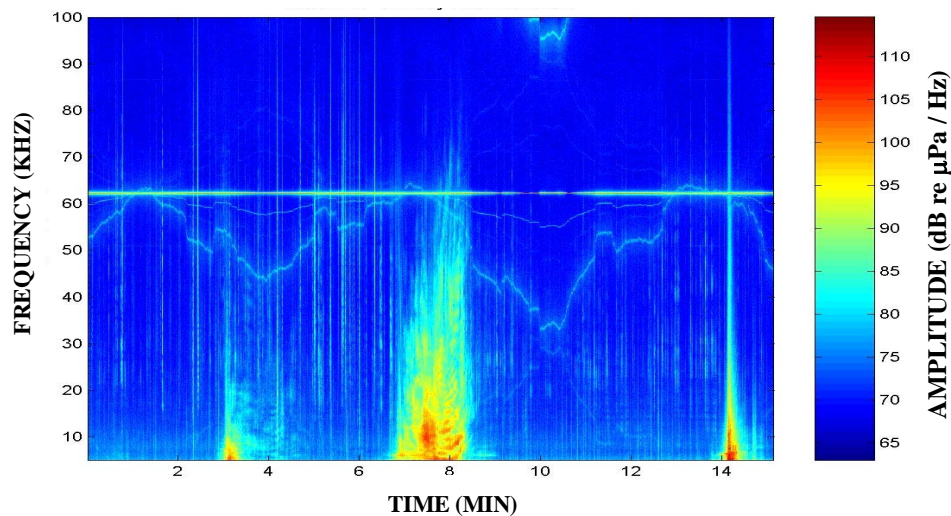


Figure 22. Broadband harbor noise, small boat, and dolphin spectra recorded on May 23 beginning at 18:30

At 20:00 on May 23 there is again evidence of small boat traffic, but also evidence of some possible dolphin activity. These dolphin appear to be at some distance from the measurement system.

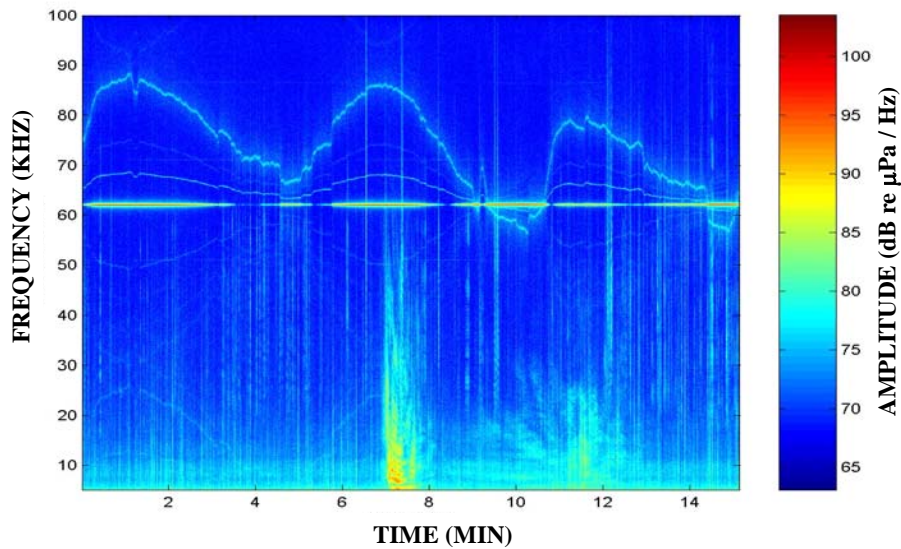


Figure 23. Broadband harbor noise, small boat, and dolphin spectra recorded on May 23 beginning at 20:00

Later in the evening of May 23, there was a considerable amount of dolphin activity observed over the 15-minute observational period (Figure 24). The levels appear strongest at the 9 and 14-minute marks.

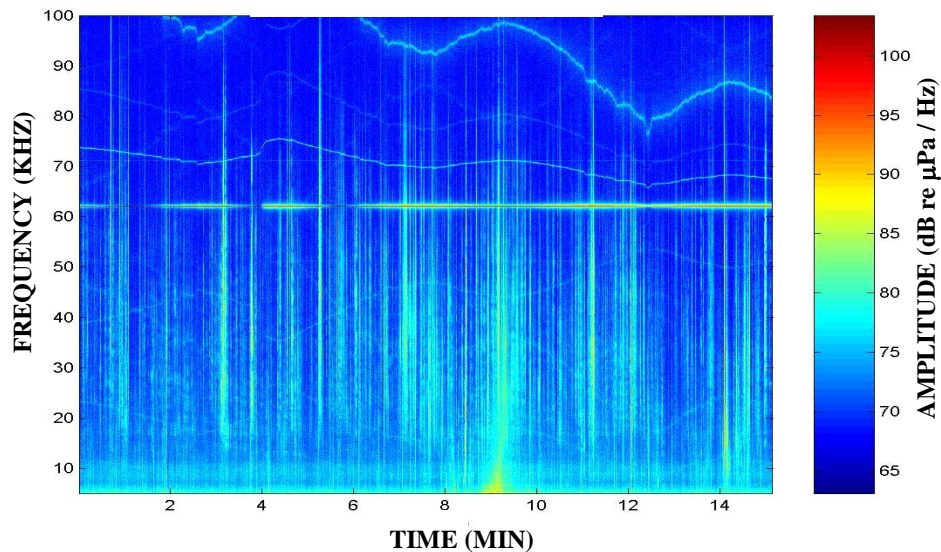


Figure 24. Broadband harbor noise and dolphin spectra recorded on May 23 beginning at 22:00

An hour later, on May 23, the dolphin activity was probably closer to the measurement system, with the strongest intensities occurring at the 4 and 12-minute marks

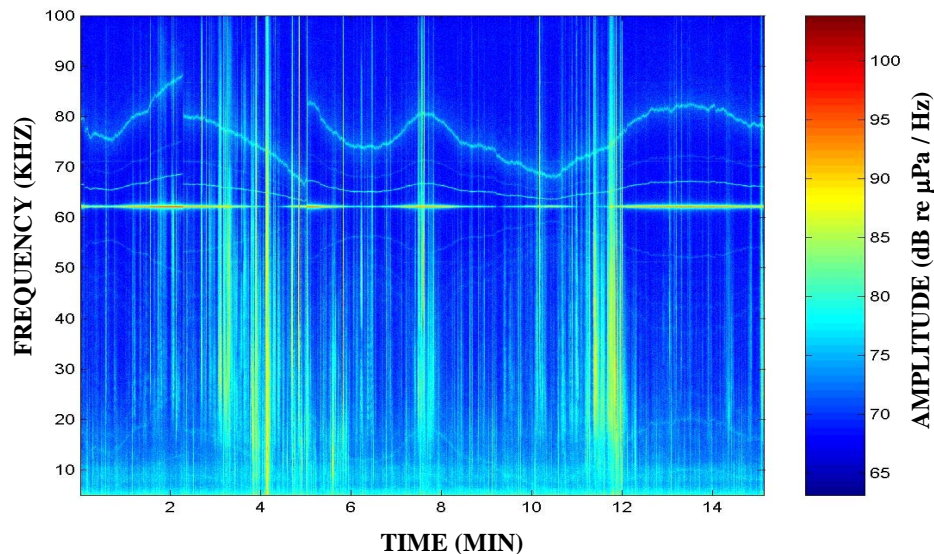


Figure 25. Broadband harbor noise and dolphin spectra recorded on May 23 beginning at 23:00

V. Summary and conclusions: In this pilot program, an ambient noise monitoring system was deployed in the entrance to the Gulfport harbor. This was a non invasive study and using passive listening techniques. This is an area with a historically high level of dolphin activity. The dolphins are regularly seen migrating in an east-west direction across the harbor entrance. In many instances, they are also seen lingering in the harbor. Most ecological and behavioral studies are done during the day time using various platforms such as airplanes, boats, but to our knowledge very little if any information is available on these animals at night. Our pilot study appears to be the very first conducted to observe the presence of dolphins in an area 24/7 on a prolonged basis using the animals echolocation features. During month of May, dolphin echo ranging clicks were regularly recorded and are easily identified by their broad band spectra. In a number of cases the spectra were correlated with visual observations of dolphin activity in the area.

The spectra of numerous small boats going in and out of the harbor were also recorded. These were visually observed and show the typical characteristic signatures of small boats. When these small boats were in the area, there was also evidence of dolphin activity. The animals did not appear to be affected by the small boat generated noise. However, when several large container ships entered and left the Gulfport harbor, there was little evidence of any dolphin echolocation signals and no dolphin were observed in the immediate area. Their absence may be due to the high levels of broadband noise radiated from these ships.

The behavior of marine mammals during the evening and early morning hours in the coastal areas of Mississippi had not been well documented. These long term observations

have shown that, even after sun set, dolphin echolocation signals were recorded. This indicates that the animals are continuing to actively hunt during the night time hours.

Future plans call for deploying a number of these systems along the Mississippi coast. The next generation system would use high density flash memory and would not require the same amount of spectral averaging that was done in this pilot study. This could have the potential of identifying individual dolphins by their characteristic echolocation signatures.

VI. Acknowledgments. The authors would like to thank the staff at The Institute of Marine Mammal Studies, and Marine Life in Gulfport Mississippi for their support during these measurements. We would also like to thank the Gulfport harbor authority for providing the pier facilities and electrical connections during the tests. A special thanks goes to Coast Guard for their help in deploying the ambient noise measurement system. This work was supported by The Institute for Marine Mammal Studies.

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